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A systematic review and meta-analysis on the effects of exercise training versus hypocaloric diet: distinct effects on body weight and visceral adipose tissue

A systematic review and meta-analysis on the effects of exercise training *versus* hypocaloric diet: distinct effects on body weight and visceral adipose tissue

SHORT TITLE: Distinct effects of exercise training *versus* diet on weight and visceral fat

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ABSTRACT

Exercise training ("exercise") and hypocaloric diet ("diet") are frequently prescribed for weight loss in obesity. Whilst body weight changes are commonly used to evaluate lifestyle interventions, visceral adiposity (VAT) is a more relevant and stronger predictor for morbidity and mortality. We performed a meta-analysis to assess the effects of exercise training or hypocaloric diet on VAT (quantified by radiographic imaging). Relevant databases were searched through May 2014. 117 Studies (n=4,815) were included. We found that both exercise and diet cause VAT loss (P<0.0001). When comparing diet *versus* training, diet caused a larger weight loss (P=0.04). In contrast, a trend was observed towards a larger VAT decrease in exercise (P=0.08). Changes in weight and VAT showed a strong correlation after diet (R^2=0.737, P<0.001), and a modest correlation after exercise (R^2=0.451, P<0.001). In the absence of weight loss, exercise is related to 6.1% decrease in VAT, whilst diet showed virtually no change (1.1%). In conclusion, both exercise and diet reduce VAT. Despite a larger effect of diet on total body weight loss, exercise tends to have superior effects in reducing VAT. Finally, total body weight loss does not necessarily reflect changes in VAT and may represent a poor marker when evaluating benefits of lifestyle-interventions.

Keywords: obesity, visceral adipose tissue, exercise training, hypocaloric diet

INTRODUCTION

The worldwide prevalence of obesity, characterized by an excess in adipose tissue, has grown to pandemic proportions.[1, 2] Multiple reviews have demonstrated that accumulation of adipose tissue in general, and in the visceral area in particular, is strongly and positively correlated with all-cause morbidity and mortality.[3] Since obesity is an important, but also modifiable, risk factor for cardiovascular and metabolic diseases [4, 5] the WHO has recommended lifestyle interventions to aim at 5-10% reduction in body weight as treatment for obesity.[6]

Caloric restriction and exercise training cause a reduction in body weight by inducing a negative energy balance in which energy expenditure exceeds caloric intake. When comparing hypocaloric diet and exercise training, previous meta-analyses revealed that dietary restriction has superior effects on weight reduction.[7, 8] However, a growing body of evidence shows that excess visceral adipose tissue (VAT) may result in more detrimental obesity-related health effects than excess body weight.[9] Indeed, increased VAT is strongly associated with insulin resistance, atherogenic dyslipidemia, and cardiovascular disease.[3, 10, 11] Moreover, a reduction in VAT improves cardiovascular and metabolic risk.[3, 12] Hence, changing VAT is considered to be more important than weight reduction in the management of obesity.

In patients with obesity, physical exercise training leads to a healthier metabolic and cardiovascular phenotype.[13-15] Whilst exercise training does not always aim to reduce body weight, exercise training in general and aerobic exercise training in particular, have potent effects on reducing VAT.[16-18] Previous meta-analyses have evaluated only the effects of caloric restriction and aerobic exercise on weight loss. The effects of these interventions on VAT have not yet been compared. Therefore, we aim to conduct a systematic review and meta-analysis to investigate the effect of caloric restriction *versus* aerobic exercise training on visceral adiposity loss in overweight and obese adults. For this purpose, we included studies that examined VAT after: 1. Caloric restriction only, 2. Exercise training only, and 3. Aerobic exercise training *versus* caloric restriction. We hypothesize that, in marked contrast to body weight loss, caloric restriction and exercise training have comparable effects on reducing VAT. With the use of a meta-regression analysis we aim to further explore the impact of intervention (e.g. duration, intensity, frequency) and subject (e.g. age, sex, baseline body weight) characteristics on the magnitude of changes in VAT.

Several international guidelines recommend lifestyle interventions aimed at a reduction in body weight of 5-10% as treatment for obesity.[6, 19, 20] Previous work, however, demonstrated that a reduction in body weight is a poor marker for VAT change.[9] Accordingly, changes in VAT may occur irrespective of changes in body weight. A hypocaloric diet causes a reduction in skeletal muscle mass, which along with a reduction in fat mass, contributes to weight loss.[21, 22] Aerobic exercise training, however, may be associated with an increase in lean body mass and/or plasma volume.[23-25] Assuming that fat mass decreases with exercise training, training may still not lead to weight loss [24, 26] Therefore, we hypothesize that the relation between changes in body weight and changes in VAT differs between caloric restriction and exercise interventions.

METHODS

Data sources and searches

The systematic literature search and documentation of literature was performed with the use of the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) statement .[27] Databases systematically searched were Pubmed, Cochrane, Web of Science and Embase. The following search strategy was used, with adaption for each database: (("Energy Intake"OR"Diet Therapy"OR"(calori*AND restrict*)"OR(low AND calori*)OR"dietary intervention*"OR"diet intervention*)"AND ("Overweight"OR"obes*")AND("Abdominal Fat"OR("Adipose Tissue"AND("intra-abdom"*ORintraabdom*ORabdom*ORvisceral*))OR"Body Composition"OR"abdominal adipos*ORvisceral adipos*ORintra-abdominal fat"OR"abdominal fat"OR"total body fat"OR"adipose tissue distribution))OR(("Overweight"OR"obes*")AND("Motor Activity"OR"Exercise"OR"Running"OR"Swimming"OR"Walking"OR"Warm-Up Exercise"OR"Exercise Therapy"OR"Motion Therapy, Continuous Passive"OR"Sports"OR "Athletic Performance"OR"Bicycling"OR"Physical Exertion"OR"running" OR"bicycling"OR"cycling"OR"walking"OR"swimming"OR"training"OR"physical activity"OR"exercis*"OR"cardio-training")AND("Abdominal Fat"OR("Adipose Tissue" AND (intra-abdom*OR"intraabdom*"OR"abdom*"OR"visceral*"))OR"Body Composition" OR"abdominal adipos"*OR"visceral adipos"*OR"intra-abdominal fat"OR"abdominal fat"OR"total body fat"OR"adipose tissue distribution")). Randomized Controlled Trials (RCTs), Non-randomized Controlled Trials (non-RCTs) OR Clinical Trials (CT) published in English, German and Dutch were included from January 1th, 1987 to May 5th, 2014. Reference lists of included articles were manually checked by RV for possible eligible studies that were missed during the literature search (Figure 1). This represents a valid and frequently used method to further increase the number of potentially eligible studies.

Study selection

To standardize the selection procedure by two independent reviewers, investigators received the local review protocol previous to the selection of studies,. After the elimination of duplicates, one investigator (RV) screened study titles for eligibility with use of the in- and exclusion criteria in the review protocol, which are listed below. Two reviewers (RV, MM) independently screened the abstracts of the remaining studies. 389 studies were assessed in full text (Figure 1). Inter-reviewer disagreements were resolved through consensus or by consulting a third reviewer (MH). When study characteristics or viable information was missing, an attempt was made to request missing information from the authors by email (n=6 studies; authors of n=2 studies provided requested information). Studies were included when the mean age at entry was ≥18 years and mean BMI was ≥25 kg/m². Studies of HIV-infected individuals were excluded because of the interference of anti-retroviral drugs with abdominal adipose tissue.[16] Because spinal cord injuries associated with changes in body composition, studies conducted in spinal cord injured individuals were also excluded.[28] Studies with one or more arms assigned to an aerobic exercise intervention or a hypocaloric diet were eligible for inclusion. For the first aim, Clinical Trials and Randomized Controlled Trials (RCTs) with one arm assigned to exercise *or* caloric restriction were selected. Furthermore, in order to directly compare duration- and energy deficit- matched exercise training with caloric restriction, RCT's with an exercise- *and* a diet-arm were included. To identify exercise and subject characteristics that predict the magnitude of change in VAT using the meta-regression analysis, clinical trials and RCT's with one arm assigned to exercise *or* caloric restriction were selected. Finally, diet and exercise studies that provided baseline and post-intervention results for VAT and weight were included for the correlation analysis. Exercise training was defined as a program including voluntary aerobic exercise at a low to vigorous intensity for at least two times per week during a minimum period of four weeks and with a minimum duration of 20 minutes per session. Caloric restriction was defined as a daily reduction in energy (caloric) intake of at least 10% of the habitual intake (2000 kcal for women, 2500 kcal for men) during a minimum period of four weeks. Interventions combining exercise and diet therapy or adding resistance exercise or bariatric surgery to an intervention arm were excluded. Studies in which a pharmacological dietary supplement was used were excluded from our analysis. Studies were eligible when VAT was measured with the use of Computerized Tomography (CT) or Magnetic Resonance Imaging (MRI). which are both considered to be the gold standard for the quantitative measurement of VAT[29]. Studies that used another measurement technique were excluded.

Data extraction and Quality assessment

Baseline and post-intervention mean VAT area or volume and standard deviation or standard error was independently recorded by two authors (RV, MM). When VAT was measured at multiple sites, the measurement at the 4^{th} and/or 5^{th} lumbar vertebrae was recorded for further analysis, since this region is most strongly correlated with body adiposity.[28] Based on changes in visceral abdominal fat area or volume, percentage change in VAT for each study was calculated by one of the authors (RV) for the correlation analysis. Percentage weight loss was also calculated based on pre- and post-intervention values. Furthermore, publication year, journal, study design, sample size, age, sex, weight, BMI, and intervention details (duration, intensity and frequency (exercise studies), caloric deficit (diet studies) were extracted from all included studies. When results were depicted in figures only (n=14 studies), data were extracted with the use of GetData Graph Digitizer. A request by email was send to the authors, when key information was not included in the published manuscript (n=6 studies). Two out of six authors responded to our repeated email requests, thus the remaining 4 studies were excluded from further analysis.

The quality of each eligible study was independently assessed by two authors (RV and MM), with the use of a modified version of The Critical Review Form for Quantitative Studies, from

Law *et al.*[30]. One item ("contamination was avoided") was not applicable for the studies included in this meta-analysis and was therefore removed for analysis. Only studies with a minimum score of 10 out of 14 items were eligible for inclusion (Figure 1).

Data synthesis and analysis

To account for potential heterogeneity between studies, a random-effects model (specified *a priori*) was used to determine the overall effect size of the intervention (exercise training or hypocaloric diet) on VAT. Effect sizes for RCTs and clinical trials were calculated as the standardized mean difference (SMD) with corresponding 95%-CI. A correlation of 0.5 between the outcomes measured in each study arm (*i.e.* exercise, diet, or control) was assumed. When a study contained multiple study arms, all were included in the statistical analysis, whereby the different intervention groups were individually compared against the control group. Analyses to assess the following comparisons: (1) diet *versus* control; (2) exercise *versus* control; (3) diet *versus* exercise were performed. The Cochrane's Q statistic and I^2 were calculated to assess the degree of heterogeneity across studies. Publication bias was assessed using visual analysis of the funnel plot asymmetry using the 'trim and fill' and the 'Classic fail 'n safe' algorithms. All calculations and plots were performed in CMA-2 (Comprehensive Meta-Analysis 2nd version, Biostat, Englewood, NJ, USA).

Meta-regression analysis

To assess the effects of subject and intervention characteristics on VAT loss, random-effects meta-regression analysis with SMD as dependent variable was calculated. The weighted inverse variance (with correction for total n) was used as weight factor. For the purpose of meta-regression analysis, the aerobic exercise arms (n=86) were separated from the hypocaloric diet arms (n=87). In both study types, duration of the exercise training or diet intervention (weeks), measurement technique (CT or MRI), body weight at baseline, age and sex were defined as a covariate. Duration was assessed as a categorical variable (duration <16 weeks *versus* duration of ≥16 weeks). In the exercise studies, intensity of the intervention was examined as a covariate. Intensity was categorized in 'vigourous intensity' (i.e. largely performed at 70% of maximal heart rate (maxHR) or >55% of maximal oxygen uptake (VO2max) or 60-80% of the heart rate reserve (HRR)), 'moderate intensity' (60-70% of maxHR, 45-55% of VO2max or at the lactate threshold), and 'low intensity' (<60% of HRmax or <45% of VO2max) based on previous work.[18] This categorization is somewhat different from the often used and more practical categories based on METs as proposed in the ACSM and AHA guidelines.[31, 32] However, only two studies included in our meta-analysis provided data on METs. Since translating percentages of maximum heart rate, heart rate reserve and VO2max into METs proves difficult with the use of average data on group level, we adopted the aforementioned strategy to divide studies based on intensity. In hypocaloric diet studies, "intensity" was divided in 'very low calorie diets' (VLCDs; reduction to maximal 800 kcal/day) and 'low calorie diets (LCDs; caloric restriction to 800-2000 kcal/day). Lastly, frequency (times spent in training per week) was added as covariate in exercise studies.

Correlation analysis

To examine correlations between weight loss and VAT improvement a Pearson correlation coefficient was calculated. The formula of the corresponding trend line was retrieved with the use of linear regression. Meta-regression analyses and correlation analysis were conducted with use of SPSS version 20.0.

RESULTS

Selection of studies for the meta-analysis

The original search resulted in 15,964 studies. Eleven more studies were found from the reference lists of the included full text papers. After removal of duplicates and elimination of papers based on the eligibility criteria and quality assessment, 50 aerobic exercise studies and 59 hypocaloric diet studies were included (Figure 1). For the analysis of a direct comparison between caloric restriction and exercise training, 8 studies were included. (Table 1) One study, which directly compared exercise training with caloric restriction was excluded as duration and energy deficit did not match between the two intervention arms. This study was included for the separate analysis of diet or exercise training only.

Cohort characteristics

A total number of 4,815 individuals (2,404 in the exercise studies, 2,411 in the hypocaloric diet studies) participated in the interventions. (Table 1) In the 8 RCT's that directly compared exercise training and caloric restriction, a total of 400 individuals were included (200 in the exercise arm, 200 in the diet arm). (Table 2) 28 studies exclusively included male subjects, whereas in 39 studies females were exclusively included. 55 studies included both sexes. Some studies recruited specific populations, which included older (aged 50-80 years) individuals (n=4); patients with type 2 diabetes (n=11), impaired glucose tolerance (n=3) and metabolic syndrome (n=3). (Table 1)

Meta-analysis

The SMD of change in VAT after exercise training was -0.47 (95%CI -0.56 to -0.39, $P<0.0001$). (Figure S1) Heterogeneity analysis showed significant heterogeneity (Cochran's Q=265.4; $I^2=68.0$). Through a funnel plot of standard error by Hedge's g and the Trim 'n Fill algorithm, publication bias was assessed. With the use of the Classic Fail 'n Safe approach, it became clear that there was no significant publication bias since 7427 missing studies would be required to achieve a p-value above 0.05. The SMD of change in VAT after caloric restriction was –0.63 (95%CI -0.71 to -0.55, *P*<0.0001) (Figure S2), whilst significant heterogeneity was present (Cochran's Q= 236.0; I^2= 63.6). In these studies, no publication bias was present since there would be 4096 studies required to achieve a p-value above 0.05. Based on the studies that directly compared exercise training and caloric restriction, exercise training caused a non-significantly larger decrease in VAT (-0.59, 95%CI -1.248 to 0.071; *P*=0.08), whilst caloric restriction caused a significantly larger weight loss than exercise training (SMD 0.308, 95%CI 0.02 to 0.60; *P*=0.04) (Figure 2). Heterogeneity analysis showed significant heterogeneity (Cochran's Q=51.9; I^2=86.5). Publication bias was assessed with the Trim 'n Fill method and showed no change in SMD when adding trimmed studies, for both the weight loss as VAT loss data.

Meta-regression analysis

No effect of measurement technique on the SMD was observed for studies that performed exercise training or diet (data not shown). In the exercise studies, univariate analysis revealed that the SMD for VAT improvement was significantly influenced by sex (R^2=0.11; 95%CI 0.06 – 0.472; *P*=0.012); duration (R^2=0.073; 95%CI -0.449 to -0.055; *P*=0.013) and frequency (R^2=0.084; 95%CI -0.157 to -0.030; *P*=0.004). The multivariate regression analysis, which included the factors that revealed a significant impact in the univariate analysis, identified an impact of male sex on SMD (R^2=0.20; 95%CI 0.066 to 0.467; *P*=0.01). In hypocaloric diet studies, univariate analysis showed a significant effect of male sex only (R^2=0.09; 95%CI 0.116 to 0.632; *P*=0.005).

Correlation analysis

For exercise studies, a moderate correlation was found between changes in weight versus changes in VAT after exercise training (R^2=0.453, P<0.001), whilst diet-interventions showed a strong correlation between the change in weight versus change in VAT (R^2=0.737, P<0.001) after caloric restriction. Exercise training showed a somewhat steeper slope compared to diet (-3.04x *versus* -2.41x, respectively), and a larger Y-axis intercept (-6.1 *versus* -1.1, respectively, Figure 3).

DISCUSSION

The present work is the first meta-analysis to compare the effect of caloric restriction and aerobic exercise training on visceral adipose tissue (VAT) loss in overweight and obese individuals. We present the following findings. First, our results confirm that both caloric restriction and exercise training successfully reduce VAT. Second, in studies that provided a direct comparison of caloric restriction and exercise training, a hypocaloric diet resulted in significantly larger weight loss. Interestingly, these studies reveal a different story for VAT. Exercise training tends to show a larger decrease in VAT compared to caloric restriction. The distinct effects of both interventions on total body weight and VAT are supported by the correlation analysis. Only a moderate correlation was found for the exercise training cohort between changes in weight and VAT. Furthermore, in the absence of weight loss, exercise training results in a 6.1% decrease in VAT, whilst a hypocaloric diet leads to virtually no change (1.1%). This suggests that evaluating only total body weight changes could lead to spurious conclusions when evaluating the efficacy of a lifestyle intervention in overweight and obese individuals since health benefits occur independent of body weight changes. Indeed, even in the absence of weight loss after exercise training, health benefits such as a reduction in VAT are present.

In line with previous meta-analyses, we found caloric restriction to have a larger effect on weight loss than exercise training.[7, 8] We extended this finding by a direct comparison of studies with matched duration and energy deficit in order to more accurately compare the impact of both interventions. In marked contrast to the superior effect of caloric restriction on weight loss, no difference in VAT reduction was observed between caloric restriction and exercise training. In fact, exercise training tended to have a superior effect on VAT reduction compared to caloric restriction. A possible mechanism underlying these different effects on weight and VAT could relate to distinct changes in body composition during these lifestyle interventions. During caloric restriction, both muscle mass and fat mass are lost, resulting in a marked decline in weight.[21, 22] During exercise training, however, lean body mass and circulating plasma volume increase, whilst fat mass decreases.[21, 23, 25, 26, 33] Previous work that directly measured these factors indeed showed that an increase in lean body mass counteracts loss of fat mass after 8 weeks of exercise training.[34] These opposing effects resulted in the absence of total body weight loss.[34] Appreciating and understanding these effects are important to acknowledge that exercise training effectively reduces VAT, despite the absence of a reduction in body weight.

In this meta-analysis, a large number of studies were included. Multivariate meta-regression analysis on these data showed that male sex is associated with a larger decrease in VAT, in both exercise and diet interventions. Other subject and intervention characteristics did not influence the magnitude of VAT loss in the multivariate model. A possible explanation that underlies the larger effect of lifestyle interventions on VAT in men is that men typically have larger VAT stores than women. As a result, this makes male participants more likely to lose VAT than female partcipants.[35] However, our meta-regression analysis showed no effect of baseline VAT area on the magnitude of VAT decrease. The exact underlying mechanisms should be subject for future research.

The distinct effects of diet and exercise training on weight and VAT suggest the presence of a different correlation between changes in body weight and VAT after caloric restriction in comparison to exercise training. Indeed, whilst a strong correlation between changes in body weight and VAT was found after caloric restriction, this correlation was only moderate for exercise training studies. This means that a change in weight after hypocaloric diet predicts a substantial effect on VAT, whereas changes in weight after exercise training only modestly predict the change in VAT. Furthermore, the trend lines for these correlations show important differences. The Y-intercept for the correlation of exercise studies is 6.1%, meaning that the absence of weight loss after exercise training is still correlated with a significant and meaningful reduction in VAT of 6.1%. In marked contrast, studies examining the impact of hypocaloric diet revealed a Y-intercept of only 1.1%, which means that in the absence of weight loss only 1.1% of VAT is lost. Furthermore, the steepness of the correlation for exercise training is slightly higher than that observed after hypocaloric diet. Taken together, these data strongly indicate that a change in weight, which is currently recommended by international guidelines for the management of obesity, does not necessarily reflect changes in VAT.

Limitations

The presence of heterogeneity of the included studies may represent a potential limitation when interpreting the results of this review. However, to correct for this heterogeneity a random effect approach was selected to perform the meta-analyses, which was specified *a priori*. Furthermore, analysis of publication bias with use of the Classic Fail ‘n Safe method showed that an unrealistically large number of studies is needed to influence the significant results obtained in our meta-analyses. Therefore, we are confident that the heterogeneity observed in the studies included in this analysis does not impact the major conclusions of our study. Another limitation might be that information about the ethnicity of participants in the included studies is lacking. Often, this information was not available in the original papers. However, we included studies that were conducted on all different continents, with exception for the African continent. We therefore believe that this meta-analysis provides conclusions applicable for every ethnic group.

Clinical relevance

As treatment for obesity, international guidelines including WHO and ACSM guidelines, recommend a minimum of 5% loss of body weight loss.[4, 6, 20] Although in common clinical practice a combination of training and hypocaloric diet is often prescribed, it is highly relevant to understand the separate effects of these interventions. Indeed, our study reveals that effects on weight loss and VAT loss are different in training and diet interventions. For example, a 5% reduction in body weight after hypocaloric diet has a different effect on VAT than a similar reduction in body weight after exercise training. Indeed, 5% loss in body weight is associated with 21.3% reduction in VAT after exercise training, but only with 13.4% reduction in VAT after a hypocaloric diet. To reduce VAT by 13.4% after exercise training, weight loss of only 2.4% is needed. Moreover, the absence of a reduction in body weight after exercise training may lead physicians to *incorrectly* conclude that the intervention has failed. This is in accordance with the ACSM position statement on appropriate physical intervention strategies for weight loss, which also emphasized that exercise training entails health benefits in the absence of weight loss.[20] In fact, it is likely that a clinically relevant VAT reduction (of 6.1%) is present in the absence of weight loss after exercise training, which may lead to reductions in cardiovascular risk and improvement in metabolic health. Therefore, it seems incorrect to recommend a 5% weight loss for all lifestyle interventions.

In conclusion, our systematic review and meta-analysis provide evidence that exercise training, despite smaller effects on reducing body weight, tends to have superior effects on reducing visceral adipose tissue compared to diet interventions in overweight and obese subjects. This suggests that changes in body weight represent a poor marker for adaptation in visceral adipose tissue, especially when performing exercise training. Our data therefore strongly indicate that, in clinical practice, caution should be taken when interpreting (lack in) changes of body weight after exercise training interventions. Incorrect conclusions can potentially lead to recommendations or suggestions that the exercise intervention was unsuccessful, despite the presence of a marked effect on body composition. Setting the correct targets for evaluating the health benefits of lifestyle interventions is therefore recommended.

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Authors' contributions statement

RJV, DJG, MTH, DHT: conception and design of research. RJV and MFM: data acquisition and analysis. RJV, MFM, ARH, MTH, DHT: interpretation results of research. RJV and MFM: preparation figures. RJV drafted manuscript. All authors edited and revised manuscript. All authors approved final version of manuscript and agree to be accountable for all aspects of the work.

Supporting Information:

Figure S1. Forest plot of the effect size (SMD) of exercise training on VAT loss. The effect size (SMD) and 95% CI for individual studies and the pooled estimate (assessed with the use of Random Effects Model) are depicted.

Figure S2. Forest plot of the effect size (SMD) of hypocaloric diet on VAT loss. The effect size (SMD) and 95% CI for individual studies and the pooled estimate (assessed with the use of Random Effects Model) are depicted.

FIGURE LEGENDS

FIGURE 1. PRISM Flowchart of outcomes of search strategy

FIGURE 2. Forest plot of the effect size (SMD) of (A) exercise training versus caloric restriction on weight loss and (B) exercise training versus caloric restriction on VAT loss. The effect size (SMD) and 95%CI for individual studies and the pooled estimate (assessed with the use of Random Effects Model) are depicted.

FIGURE 3. Correlation between %VAT improvement and %weight loss for exercise studies (R^2=0.4531, $P<0.001$; trendline: $y = -3.03x - 6.1$), and caloric restriction studies (R^2=0.737, $P<0.001$; trendline: $y = -2.46x - 1.1$).

Table 1 Overview of the characteristics of the included Exercise training (n=50) and Hypocaloric diet (n=59) studies.

Exercise Training Studies										
Reference	**Groups**	**N (M/F)**	**Age (years)**	**BMI (kg/m²)**	**Intensity**	**Frequency/ duration per session**	**Dura-tion (weeks)**	**Assess-ment VAT**	**Results VAT (pre / post)**	**Weight (kg) (pre/post)**
Baria et al.[36]	Centre-based exercise Home-based exercise Control	10 (10/0) 8 (8/0) 10 (10/0)	52.1 ± 11.4 50.8 ± 7.7 53.4 ± 9.6	30.8 ± 5.1 30.9 ± 3.9 29. ± 1.9	Personal ventilatory treshold	3x/week / 30-60min	12	CT L4-L5 (mm)	113.1 ± 24.1 / 106.6 ± 22.8 115.2 ± 20.5 / 107.4 ± 17.0 92.1 ± 25.9 / 97.0 ± 23.9	86.2 ± 19.4 / 86,1 ± 20.7 90.9 ± 12.4 / 89.3 ± 11.9 84.8 ± 7.8 / +1.5kg
Boudou et al.[37]	Exercise Control	8 (8/0) 8 (8/0)	42.9 ± 5.2 47.9±8.35	28.3 ± 3.9 30.85±5.2	75% of VO2peak **&** 5 x 2 min 85% of VO2peak alternated by 3x 50% of VO2peak	2x/week / 45 min & 1x/week / 19 min	8	MRI L4-L5 (cm²)	153.25± 38.55/ 84.20±21.30 156.85±23.40 / 150.35±23.3	86.90 ± 13.4/ 85.00 ±13.8 85 ± 13.75 / 88.75 ± 1.30
Cho et al.[38]	Low-intensity exercise High-intensity exercise Control	15 (0/15) 15 (0/15) 15 (0/15)	42.4 ± 7.6 45.6 ± 4.6 49.2 ± 8.7	25. 6 ± 1.7 25.1 ± 2.0 26.1 ± 2.7	40-50% of VO2max 70-75% of VO2max	3/week (duration depending on energy expenditure)	12	CT L4-L5 (cm²)	99 ± 41 / 79 ± 40 90 ± 26 / 83 ± 30 106 ± 33 / 103 ±28	64.4 ± 6.0 / 62.3 ± 5.5 63.2 ± 6.4 / 60.4 ± 6.4 63.0 ± 7.8 / 64.5 ± 7.0
Cuff et al.[39]	Aerobic exercise Control	9 (0/9) 9 (0/9)	59.4 ± 1.9 60.0 ± 2.9	32.5 ± 1.4 36.7 ± 2.0	60-75% maxHR	3x /week / 75 min	16	CT L4-L5 (cm²)	215.7 (25.8) / -8.8 (5.4) 225.8 (8.9) / - 0.4 (12.0	81.2 ± 3.8 / -1.2 (0.7) 95.6 ± 6.5 / +2.0 (1.2)
Davidson et al.[40]	Aerobic exercise Control	37 (17/20) 28 (11/17)	68.8±6.0(m) 69.1±6.5 (f) 67.4±3.8(m) 66.7 ± 3.7(f)	29.9 ± 3.0 29.2 ± 3.7 30.5 ± 2.0 30.4 ± 3.2	60-75% of VO2peak	7x/week / 30 min	26	MRI (kg)	-11.0 (1.9)% -0.7 (2.5)%	NR / -2.7 (3.1)% NR / -0.1 (0.7)%
Dekker et al.[41]	Obese with T2D Obese	8 (8/0) 8 (8/0)	51.0 (3.0) 47.1 (3.1)	29.9 (1.2) 32.4 (0.6)	60% VO2max	5x/week / 60 min	12	MRI L4-L5 (kg)	3.8 (0.3) / 3.1(0.4) 4.0 (0.4) /3.4 (0.4)	93.5 (2.9) / 93.9 (3.2) 97.6 (3.4) / 97.2 (0.6)
Despres et al.[42]	Aerobic exercise	13 (0/13)	38.8 ± 5.3	34.5 ± 4.3	55% of VO2max	4-5x/week / 90 min	12	CT L4-L5 (cm²)	124.7 ± 48.6 / 121.3 ± 45.5	90.0 ± 11.8 / 86.3 ± 9.6

Reference	Groups	N (M/F)	Age (years)	BMI (kg/m²)	Intensity	Frequency/ duration per session	Duration (weeks)	Assessment VAT	Results VAT (pre / post)	Weight (kg) (pre/post)
Dipietro et al.[43]	Aerobic exercise Control	9 (2/7) 7 (1/6)	72 (1) 73 (1)	27.5 (2.7) 26.8 (1.5)	55% of maxHR during 1 month 75% during 3 months	4x/week / 40-60min	17	CT L4-L5 (cm²)	116 (31) /106 (24) 136(28) / 118 (27)	65 (5) / 64(4) 69 (4) / 69(4)
Donges et al.[44]	Aerobic exercise Control	13 (13/0) 8 (8/0)	45.4 (1.7) 49.5 (2.6)	32.0 (1.3) 29.6 (2.1)	75% of age-predicted maxHR during first 4 weeks, thereafter 80% of maxHR	3x/week / 40-50min	12	CT L4 (cm²)	1371 (113) / 1222 (100) 1383 (164) / 1349 (145)	103.1 (4.6) / -1.9 (0.7)% 92.2 (6.9) / + 0.1(0.6)%
Donges et al.[45]	Aerobic Control	41 (16/25) 26 (13/13)	NR	30.0 ± 5.5 28.3 ± 4.1	70-75% of max HR	3x/week / 30-50min	10	DEXA (kg)	1.49 ± 0.55 / 1.38 ± 0.58 1.44 ± 0.43 / 1.44 ± 0.45	84.8 ± 18.6 / -0.8 ± 1.9 83.2 ± 13.4 / +0.6 ± 1.3kg
Donnelly et al.[46]	Exercise Group men Control Group men Exercise group women Control group women	16 (16/0) 15 (15/0) 25 (25/0) 18 (18/0)	22 ± 4 24 ± 4 24 ± 5 21 ± 4	29.7 ± 2.9 29.0 ± 3.0 28.7 ± 3.2 29.3 ± 2.3	60% of HRR with a gradual increase to 75% at 6 months	5x/week / 20-45min	65	CT L4-L5 (cm²)	97.9 ± 22.5 / 75.5 ± 18.3 91.7 ± 29.7 / 85.4 ± 39.7 60.6 ± 25.5 / 57.4 ± 28.4 62.9 ± 21.8 / 66.0 ± 13.9	94.0 ± 12.6 / 88.8 ± 9.5 94.1 ± 11.4 / 93.16 ± 11.6 77.0 ± 11.4 / 77.6 ± 12.8 79.9 ± 8.1 / 82.8 ±9.2
Friedenreich et al.[47]	Aerobic exercise Control	160 (0/160) 160 (0/160)	61.2±5.4 60.6±5.7	29.14.5 29.3 ± 4.3	70-80% of maxHR	3.6x/week / 45min	52	CT umbilicus (cm²)	101.4 ± 55.4 / -16.5 103.2 ± 56 / -1.6	75.6 ± 13.0 / -2.3 76.3 ± 12.7 / -0.5
Gan et al.[48]	Aerobic exercise	18 (0/18)	37.4 (1.3)	30.9 (0.7)	55-70% VO2max	4-5x/week / 40min	9.7	MRI L4-L5 (l)	2.23 (0.12) / 2.11 (0.12)	94.1 (2.0) / 92.8 (2.0)
Giannopoulou et al.[49]	Aerobic exercise	11 (0/11)	57 (entire study)	35.9 (2.2)	70% HRR	3x/week / 60-75min	12	MRI (cm³)	5204 (598) / 4675 (550)	92.9 (6) / 91.2 (5.6)

Reference	Groups	N (M/F)	Age (years)	BMI (kg/m²)	Intensity	Frequency/ duration per session	Dura-tion (weeks)	Assess-ment VAT	Results VAT (pre / post)	Weight (kg) (pre/post)
Halverstadt et al.[50]	Aerobic exercise	83 (34/49)	57.9 ± 0.6	36.0 ± 1.1 (% body fat)	50% of VO2max with a gradual increase to 70% of VO2max (for at least 14 w)	3x/week / 20-40min and addition of one extra low intensity exercise session	24	CT (cm²)	127.8 (4.5) / -14.4 (2.4)	80.6 ± 1.6 / -1.1 (0.3)
Haus et al.[51]	Aerobic exercise	16 (5/11)	65 ± 1	33 ± 1	60-65% max HR with a gradual increase to 80-85% week 4	5x/week / 50-60min	12	CT (cm²)	182.4 ± 21.5 / 134.5 ± 15.9	95.7 ± 4.1 / 91.9 ± 3.8
Heydari et al.[52]	Aerobic exercise Control	25 (25/0) 21 (21/0)	24.7 ± 4.8 25.1 ± 3.9	28.4 ± 0.5 29 ± 0.9	80-90% of max HR during 8 sec sprint, whereafter 12 sec recovery	3x/week / 20min	12	CT L4/L5 (g)	62.6 (6.2) / 51.8 (5.1) 69.7 (9.7) / 67.3 (8.4)	87.8 ± 2.7 / 86.3 ± 2.7 89 ± 2.9 / 89.4 (3.1)
Hutchison et al.[53]	Obese PCOS	8 (0/8) 14 (0/14)	NR	36.9 (2.1)	75-85% of maxHR OR HIIT: 6-8 x 5 minutes at 95-100% of maxHR – 1-2 min recovery	3x/week / 60 min (alternating between HIIT and continuous)	12	CT L4-L5 (cm²)	135.1 (15.7) / 132.7 (18.1) 119.5 (16.1) / 107.6 (15.1)	99.4 (5.4) / 96.9 (4.5) 96.9 (4.8) / 95.3 (4.8)
Irving et al.[54]	Low-intensity exercise High-intensity exercise Controls	11 (0/11) 9 (0/9) 7 (0/7)	51 ± 9 (entire group)	34.7 ± 7.5 34.7 ± 6.8 32.7 ± 3.8	At lactate threshold Midway between lactate threshold and VO2max (3 days) ; lactate threshold (2 days)	5x/week / duration depended on energy expenditure	16	CT L4/L5 (cm²)	153 ± 51 / 146 ± 49 173 ± 73 / 148 ± 59 157 ± 71 / 155 ± 71	97.2 ± 22 / 95.1 ± 19.3 93.5 ± 18.3 / 90.0 ± 15.6 89.6 ± 11.2 / 88.7 ± 10.6

Reference	Groups	N (M/F)	Age (years)	BMI (kg/m²)	Intensity	Frequency/ duration per session	Duration (weeks)	Assessment VAT	Results VAT (pre / post)	Weight (kg) (pre/post)
Irwin et al.[55]	Exercise Control	87 (0/87) 86 (0/86)	60.7 ± 6.7 60.6 ± 6.8	30.4 ± 4.1 30.5 ±3.7	Start 40% of maxHR with a gradual increase to 60-75% by week8	5x/week / 45min	52	CT L4-L5 (g/cm²)	147.6 (134.3-161) / -8.5 147.6 (135.4-159.8) / +0.1	81.4 ± 14.1 / -1.3% 81.7 ± 12.1 / 0.1%
Janssen et al.[56]	Aerobic exercise in black men Aerobic exercise in white men Aerobic exercise in black women Aerobic exercise in white women	84 (84/0) 255 (255/0) 160 (0/160) 243 (0/243)	Not depicted for entire groups	27.0 ± 4.8 26.7 ± 4.9 28.2 ± 6.1 24.9 ± 4.8	75% of VO2max	3x/week / 50 min	20	CT L4-L5 (cm²)	77.5 ± 5.1 / 71.9 ± 52.2 109.5 ± 63.6 / 102.4 ± 61.2 69.1 ± 40.8 / 65.4 ± 37.9 75.4 ± 52.7 / 72.2 ± 49.1	83.9 ± 16.3 / - 0.5 ± 2.4 84.3 ± 16.3 / -0.3 ± 2.1 73.8 ± 16.3 / -0.4 ± 3.0 67.0 ± 13.6 / -0.1 ± 2.1
Johnson et al.[57]	Aerobic exercise Stretching control	12 (N.R.) 7 (N.R.)	49.1 (2.3) 47.3 (3.6)	32.2 (0.8) 31.1 (1.1)	Week 1: 50% of VO2p Week 2: 60% VO2p Week 3 and 4: 70% VO2p	3x/week / 30-45 min (interval:15 min training, 5 min rest)	4	MRI L4-L5 (cm²)	154.3 (18.3) / 143.6 (18.7) 154.3 (21.2) / 158.6 (23.9)	94.4 (3.8) / 94.1 (4.0) 98.8 (6.0) / 98.6 (6.3)
Jung et al.[58]	Moderate intensity Vigorous intensity Control	8 (0/8) 8 (0/8) 12 (0/12)	56.8 ± 8.2 48.4 ± 6.1 55.5 ± 7.6	25.5 ± 1.5 25.9 ± 1.6 27.7 ± 3.4	Goal: intensity at 3.5- 5.2 METs Goal: intensity at > 5.3 METs	5x/week / 60min (moderate intensity) vs. 30min (vigourous intensity)	12	CT L4-L5 (cm²)	15784.6±4662.7 / 13262.5 ± 3217.8 13726.6±3011.8 / 12447.4 ± 2252.6 17790.2±5621.7 / 17372.7 ± 5235.7	63.7 ± 5.0 / -2.9% ± 2.5% 62.9 ± 4.4 / -2.5% ± 2.3% 67.3 ± 9.8 / -1.5% ± 1.6%
Karstoft et al.[59]	Continuous walking group Interval walking group Control group	12 (8/4) 12 (7/5) 8 (5/3)	60.8 ± 2.2 57.5 ± 2.4 57.1 ± 3.0	29.9 ± 1.6 29.0 ± 1.3 29.7 ± 1.9	>55% of peak energy expenditure Walking at 70% of peak energy expenditure for 3 minutes, alternated with 3 minutes of slow walking	5x/week / 60min	17	MRI, below diaphragm (l)	4.5 ± 0.3 / 4.2 ± 0.4 4.7 ± 0.8 / 4.2 ± 0.7 4.7 ± 0.4 / 4.6 ± 0.4	88.2 ± 4.7 / 87.5 ± 4.8 84.9 ± 4.9 / 80.7 ± 4.1 88.5 ± 4.7 / 89.2 ± 5.2

Reference	Groups	N (M/F)	Age (years)	BMI (kg/m²)	Intensity	Frequency/ duration per session	Duration (weeks)	Assessment VAT	Results VAT (pre / post)	Weight (kg) (pre/post)
Kim et al.[60]	Aerobic exercise	24 (24/0)	49.4 ± 9.6	30.7 ± 3.3	Gradual increase of 50-60% of maxHR to 60-70%	3x/week / 60min	12	CT L4-L5 (cm²)	197.1 ± 61.9 / 165.7 ± 57.0	87.7 ± 11.2 / -4.2%
Ku et al.[61]	Aerobic exercise	15 (0/15)	55.7 ± 7.0	27.1 ± 2.4	40-50% of maximal exercise capacity	5x/week / 60min	12	CT (g)	15890 ± 4593 / 15038 ± 3369	66.3 ± 6.0 / -1.9 ± 1.2
	Control	16 (0/16)	57.8 ± 8.1	27.4 ± 2.8					17530 ± 4747 / 17362 ± 4728	67.6 ± 7.5 / -0.6 ± 0.7
Kwon et al.[62]	Aerobic exercise	13 (0/13)	55.5 ± 7.5	27.0 ± 2.5	Anaerobic threshold	5x/week / 60min	12	CT L4-L5	16291.5±4808/ 14682.7±3494	66.3 ± 6.5 / NR
	Control	14 (0/14)	57.5 ± 8.6	27.5 ± 3.0					17204.5±4674/ 17216.3±4560	68.0 ± 7.9 / NR
Lee et al.[63]	Obese	8 (8/0)	47.1 ± 8.1	32.4 ± 1.6	~60% of VO2peak	5x/week / 60min	13	MRI 5cm below to 15 cm above L4-L5 (kg)	9.2 ± 1.2 / 8.3 ± 1.1	97.6 ± 8.9 / 97.2 ± 8.9
	T2D	9 (9/0)	51.0 ± 8.0	29.9 ± 3.2					7.5 ± 1.3 / 6.7 ± 1.5	93.5 ± 7.6 / 93.9 ± 8.5
Liao et al.[64]	Aerobic exercise	32 (9/23)	55.8 (1.8)	25.6 (0.8)	50% of HRR, with a gradual increase to 70%	3x/week / 60min	26	CT (cm²)	86.3 (8.1) / -16.1	66.1 (2.9) / -2.7 (0.4)
	Stretching control group	32 (17/15)	52.2 (1.8)	26.6 (0.8					112.3 (9.9) / -14.5	69.7 (2.6) / -0.9 (0.3)
Malin et al.[65]	Aerobic exercise	35 (16/19)	66.8 ± 0.8	35.1 ± 0.7	60-65% of maxHR first four weeks, thereafter increase to 80-85%	5x/week / 50-60min	12	CT (cm³)	151.4 (14) / -30.6	99.0 ± 2.4 / - 8.1 ± 0.7
Malin et al.[66]	Impaired fasting glucose	12 (8/4)	65.1 ± 0.6 (entire group)	33.8 ± 1.0	60-65% of maxHR first four weeks, thereafter increase to 80-85%	5x/week / 50-60min	12	CT (cm²)	139.9 ± 16.8 / 86.6 ± 14.4	100 / 89.9
	Impaired glucose tolerance	9 (4/5)		32.7 ± 1.1					215.9 ± 76.6 / 140.9 ± 45.2	94.5 / 87.3
	Combined glucose intolerance	22 (7/15)		35.6 ± 1.0					187.7 ± 19.1 / 172.2 ± 19.9	96.9 / 90.1
	Normal glucose	15 (4/11)		32.3 ± 1.2					137.4 ± 23.9 /	90.1 / 84.5

	tolerant Type 2 diabetes	18 (7/11)		34.1 ± 1.3					90.5 ± 21.2 139.9 ± 23.7 / 109.0 ± 18.1	94 / 90.4
Reference	**Groups**	**N (M/F)**	**Age (years)**	**BMI (kg/m²)**	**Intensity**	**Frequency/ duration per session**	**Dura-tion (weeks)**	**Assess-ment VAT**	**Results VAT (pre / post)**	**Weight (kg) (pre/post)**
McKenzie et al.[67]	Males, GG genotype Males, GT + TT genotype Females, GG genotype Females, GT + TT genotype	29 (29/0) 21 (21/0) 38 (0/38) 20 (0/20)	58 ± 1 61 ± 1 57 ± 1 58 ± 1	28.7 ± 0.7 27.3 ± 0.8 27.7 ± 0.7 27.9 ± 1.0	50-70% of HRR	3-4x/week / 20-40min	24	CT (cm²)	150 (129-175) / -20.1 (5.6) 131 (110-156) / -29.9 (9.2) 110 (100-121) / -7.9 (3.1) 111 (97-127) / -0.2 (5.6)	91.1 ± 2.7 / -1.3 86.7 ± 3.1 / -2.3 73.8 ± 2.0 / -0.4 76.0 ± 2.8 / -1.1
McTiernan et al.[68]	Women, aerobic exercise Women, controls Men, exercisers Men, controls	49 (0/49) 51 (0/51) 51 (51/0) 51 (51/0)	54.4 ± 7.1 53.7 ± 5.6 56.2 ± 6.7 56.6 ± 7.6	28.9 ± 5.5 28.5 ± 4.5 29.7 ± 3.7 30.1 ± 4.8	60-85% of maxHR	6x/week / 60min	52	CT L4-L5 (cm²)	105.9 ± 60.8 / 100.1 ± 58.8 102.6 ± 55.8 / 104.2 ± 59.6 161.8 ± 66.3 / 149.6 ± 76.6 176.7 ± 79.1 / 170.5 ± 73.3	78 ± 17.8 / -1.4 ± -1.8% 77.9 ± 12.8 / +0.7 ± 0.9% 94.8 ± 14.9 / -1.8 ± -1.9% 97.4 ± 18.2 / +0.7 ± 0.9%
Miyatake et al.[69]	Aerobic exercise	25 (25/0)	NR	28.5 ± 2.3	60% of maximum HR and walking of an extra 1000 steps/day	1x/week supervised and daily walking / duration NR	52	CT (cm²)	109.8 ± 57.2 / 82.7 ± 42.6	81.3 ± 7.9 / 78.1 ± 7.4
Moghadesi et al.[70]	Aerobic exercise Control	8 (8/0) 8 (8/0)	NR	30.3 ± 2.1 32.0 ± 5.3	Walking 2 miles on 40-59% VO2max	4x/week / 30min	12	MRI L4-L5 (cm³)	651.1 ± 31.8 / 602.2 ± 13.7 688.4±106.2/ 692.2 ± 108.8	86.1 ± 4.6 / 84.1 ± 4.3 90.4 ± 13.9 / 90.6 ± 14.1
O'Leary et al.[71]	Aerobic exercise	16 (5/11)	63 (1)	33.2 (1.4)	Start at 60-65% of maxHR with a gradual increase to 80-85%	5x/week / 50-60min	12	CT L4-L5(cm²)	175.6 (20.2) / 136.2 (16.9)	94.1 (4.3) / 90.9 (4.0)

Reference	Groups	N (M/F)	Age (years)	BMI (kg/m²)	Intensity	Frequency/ duration per session	Duration (weeks)	Assessment VAT	Results VAT (pre / post)	Weight (kg) (pre/post)
Park et al.[72]	Aerobic exercise Control	10 (0/10) 10 (0/10)	42.2 ± 1.91 43.1 ± 1.67	25.3 ± 1.74 25.5 ± 0.86	60-70% of maxHR	6x/week / 60min	24	CT umbilicus	195.0 ± 12.55 / 112.4±10.50 182.9 ± 16.81 / 190.4±15.74	63.7 ± 2.58 / - 4.7 kg 65.2 ± 1.87 / +0.6kg
Prior et al.[73]	Aerobic exercise	34 (34/0)	62 ± 1	28.9 ± 0.7	50-70% of VO2max	3x/week / 20-45min	26	CT L4-L5 (cm²)	154 (13) / 138.3	91.4 ± 2.4 / -1.6%
Pritchard et al.[74]	Aerobic exercise	14 (14/0)	21.0 ± 0.8	26.2 ± 5.5	50-55% of VO2max	7x/week / 57min	13	CT L4-L5 (cm²)	80.8 ± 19.0 / 52.1 ± 22.4	82.1 ± 19.9 / 77.1 ± 19.0
Redman et al.[75]	Aerobic exercise	8 (0/8)	25 ± 1	32.0 ± 1.6	55% of VO2max	5x/week / 23min week 1-4; gradual increase to 58min week 12-16	16	MRI (kg)	1.3(0.9-1.9) / 1.2 (0.7-1.7)	84.6 ± 5.8 -1 ± 2%
Reichkendler et al.[76]	Moderate dose aerobic exercise High dose aerobic exercise Control	18 (18/0) 18 (18/0) 17 (17/0)	30 ± 2 28 ± 1 31 ± 1	28.6 ± 0.4 27.6 ± 0.3 28.0 ± 0.6	VO2max > 70% VO2max 50-70%	3x/week / duration depended on EE 4x/week / duration depended on EE	11	MRI L4-L5 (kg)	2.2 ± 0.8 kg / 1.9 ± 0.6 kg 2.0 ± 0.7 kg / 1.6 ± 0.4 kg 2.0 ± 0.6kg / 2.1 ± 0.6 kg	93.2 ± 1.9 / 89.6 ± 2.0 91.3 ± 1.7 / 88.8 ± 1.6 92.8 ± 2.1 / 92.9 ± 2.1
Sasai et al.[77]	Moderate intra-abdominal fat High intra-abdominal fat	33 (33/0) 24 (24/0)	52.9 ± 10.6 53.5 ± 9.5	29.2 ± 3.1 30.3 ± 3.1	Anaerobic treshold	3x/week / 90min	12	CT (cm²)	149.7 ± 35.4 / 134.6 ± 43.1 242.4 ± 34.4 / 199.1 ± 39.7	80.9 ± 10.1 / -2.3 ± 2.2 88.8 ± 11.3 / -3.2 ± 3.0
Sasai et al.[78]	Low volume exercise High volume exercise	19 (19/0) 18 (18/0)	49.7 ± 8.2 45.4 ± 8.6	31.0 ± 4.1 29.3 ± 2.0	65-80% of maxHR	3x/week / 30-60min	12	CT (cm²)	188.1 ± 53.9 / 170.3 ± 46.6 167.9 ± 44.3 / 137.9 ± 40.6	89.8 ± 13.4 / -2.7 ± 3.1 85.7 ± 9.6 / -3.4 ± 2.6
Schwartz et al.[79]	Young men Older men	13 (13/0) 15 (15/0)	28.2 ± 2.4 67.5 ± 5.8	26.0 ± 3.5 26.2 ± 2.7	50-60% of HRR with a gradual increase to 85%	5x/week / 45min	27	CT (cm²)	66.3 ± 37.1 / 54.8 ± 33.6 144.5 ± 49.4 /	85.1 ± 15.0 / 84.6 ± 13.4 79.6 ± 7.9 /

									109.0 ± 44.9	77.1 ± 7.8
Reference	**Groups**	**N (M/F)**	**Age (years)**	**BMI (kg/m²)**	**Intensity**	**Frequency/ duration per session**	**Dura-tion (weeks)**	**Assess-ment VAT**	**Results VAT (pre / post)**	**Weight (kg) (pre/post)**
Shojaee-Moradie et al.[80]	Aerobic exercise Control	10 (10/0) 7 (7/0)	47 ± 3 55 ± 4	27.6 ± 0.6 27.6 ± 0.9	60-85% of VO2max	3x/week / >20min	6	CT L4-L5 (cm²)	169.8 ± 13.1 / 139.2 ± 10.0 197.0 ± 25.6 / 181.4 ± 26.7	87.4 ± 2.8 / 87.6 ±2.6 84.1 ± 2.5 / 83.3 ± 2.4
Sigal et al.[81]	Aerobic training group Control	60 (39/21) 63 (41/22)	53.9 ± 6.6 54.8 ± 7.2	35.6 ± 10.1 35.0 ± 9.5	60-75% of max HR	3x/week /15-45min	22	CT L4-L5 (cm²)	257 ± 161 / 244 ± 161 252 ± 147 / 250 ± 147	103.5 ± 31.0 /100.9 ± 30.2 101.3 ± 28.6 /101.0 ± 27.8
Slentz et al.[82]	Low Amount, moderate intensity Low Amount, vigorous intensity High amount, vigorous intensity Control	40 (22/18) 46 (23/23) 42 (23/19) 47 (23/24)	54.0 ± 5.5 53.0 ± 7.0 51.5 ± 5.3 52.3 ± 7.7	29.8 ± 3.2 29.7 ± 3.1 29.1 ± 2.4 29.8 ± 3.0	40-55% of VO2max in order to reach walking 19.2km/week 65-80% of VO2max in order to reach jogging 19.2km/week 65-80% of VO2max in order to reach levels of jogging 32.0km per week	Duration and frequency depended on set goal for distance/intensity	34-39	CT at L4 pedicle	173 ± 72 / +1.7 ± 19.7% 154 ± 55 / +2.5 ± 21.3% 168 ± 64 / -6.9 ± 20.8% 165 ± 68 / +8.6 ± 17.2%	88.0 ± 16.3 / -0.7% 85.0 ± 13.4 / -0.8% 85.7 ± 12.2 / -2.6% 86.9 ± 14.2 / -1.0%
Solomon et al.[83]	Aerobic exercise and low glycemic index isocaloric diet Aerobic exercise and high glycemic index isocaloric diet	10 (2/7) 12 (5/7)	67 (2) 64 (1)	34.9 (1.1) 34.1 (1.1)	~85% of maximum heart rate	5x/week / 60min	12	CT (cm²)	106.9 (12.7) / 78.7 (12.1) 117.5 (26.3) / 73.0 (18.5)	97.4 (3.8) / 89.6 (3.4) 94.7 (4.4) / 85.7 (4.1)

Reference	Groups	N (M/F)	Age (years)	BMI (kg/m²)	Intensity	Frequency/ duration per session	Duration (weeks)	Assessment VAT	Results VAT (pre / post)	Weight (kg) (pre/post)
Yassine et al.[84]	Aerobic exercise	12 (NR)	64 ± 2	35.3 ± 5.8	Initially 60-65 of maxHR with a gradual increase to 80-85%	5x/week / 50-60min	12	CT (cm²)	192.3 ± 104.3 / 158.4 ± 87.0	99.7 ± 15.7 / 95.9 ± 14.6
Yoshimura et al.[85]	High liver fat group Low liver fat group	13 (5/8) 14 (6/8)	NR	30.2 ± 5.7 25.5 ± 3.2	Lactate treshold	3/week / 60min	12	CT L4-L5 (cm²)	213 ± 63 / 187 ± 66 139 ± 59 / 116 ± 61	78.3 ± 17.1 / -3.6% 66.0 ± 11.8 / -3.3%

Hypocaloric diet studies

Reference	Groups	N (M/F)	Age (years)	BMI (kg/m²)	Caloric restriction	Duration (weeks)	Assessment VAT	Results VAT (pre / post)	Weight (kg) (pre/post)
Alvarez et al.[86]	Obese, old Obese, young	6 (6/0) 6 (10/0)	60 (2.7) 32.9 (2.3)	28.9 (1.1) 30.4 (1.0)	Reduction of 500-800 kcal/day	13	CT (cm²)	184 (27) / 140 (31) 135 (17) / 107 (14)	91.2 (4.1) / 83.9 (4.0) 97.9 (4.3) / 90.2 (3.8)
Banasik et al.[87]	VLCD	15 (2/13)	39.6 ± 13.4	36.2 ± 6.3	Restriction to 800 kcal/day	4	CT L4-L5 (cm²)	139.8 ± 82 / 120.8±85.9	104.1 ± 26.8 / 97.3 ± 26.4
Bosy-Westphal et al.[88]	LCD	30 (0/30)	31.4 ± 6.0	35.5 ± 4.9	Restriction to 800-1000 kcal/day	14.2	MRI (cm³)	1757 ± 826 / 1530 ± 755	101.0 ± 18.3/ 91.2 ± 17.4
Brochu et al.[89]	LCD	71 (0/71)	58.0 ± 4.7	32.2 ± 4.6	Reduction of 500-800 kcal of baseline resting metabolic rate (determined by indirect calorimetry)	26	CT L4-L5 (cm²)	186 ± 56 / -23 ± 30	83.6 ± 14.4 / - 5,1 ± 4,7
Chan et al.[90]	Hypocaloric diet Isocaloric diet	20 (20/0) 15 (15/0)	46 ± 8 (entire group)	35 ± 1.0 31 ± 0.7	reduction in energy intake by ~33%	16	MRI (kg)	7.1 (0.5) / 5.4 (0.4) 6.9 (0.4) / 6.7 (0.4)	109 (2) / 96 (3) 105 (3) / 109 (2)
Colles et al.[91]	VLCD	32 (19/13)	47.5 ± 8.3	47.3 ± 5.5	Restriction to 456-680 kcal/day	12	CT and MRI L2-L3 (cm²)	346.3 ± 103.3 / 285.1 ± 89.3	139.8 ± 11.0/ 125.0 ± 11.7

Reference	Groups	N (M/F)	Age (years)	BMI (kg/m²)	Caloric restriction	Duration (weeks)	Assessment VAT	Results VAT (pre / post)	Weight (kg) (pre/post)
Collins et al.[92]	LCD	30 (3/27)	53	56.0 (1.0)	Restriction to 800kcal/day	9	CT (cm²)	388.0 (31.2) / 342.1 (23)	NR
Conway et al.[93]	VLCD and LCD in black women VLCD and LCD in white women	8 (0/8) 10 (0/10)	34.8 ± 7.2 38.6 ± 6.3	40.0 ± 5.0 38.2 ± 8.1	During first twelve weeks: restriction to 800 kcal/day During week 12-24: restriction to 1200-1500 kcal/day	24	CT L4-L5(cm²)	105 (25) / 74 (23) 160 (70) / 105 (63)	NR
Cooper et al.[94]	LCD	(2/43)	47.5 ± 6.2	44.0 ± 6.6	Restriction to 1200-2100 kcal/day	52	CT (cm²)	186.9 ± 62.9 / -28.7 ± 46.	118.6 ± 16.6/ -8.8 ± 5.9
Dengo et al.[95]	LCD Control	36 (15/11) (combined groups)	61.2 (0.8) 66.1 (1.9)	30.0 (0.6) 31.8 (1.4)	Restriction to 1200-1500 kcal/day	12	CT (cm²)	177 (15) / 133 (12) 188 (18) / 186 (17)	84.6 (2.6) / 77.5 (2.2) 91.0 (4.8) / 90.4 (4.9)
Trussardi Fayh et al.[96]	LCD only	18 (6/12)	30.1 ± 5.5	34.7 ± 2.4	Reduction of 500-1000 kcal/day	11.4	CT L4-L5 (cm²)	136.1 ± 64.0 / 112.5 ± 54.0	95.8 ± 13.7 / 91.5 ± 14.2
Fisher et al.[97]	LCD	29 (0/29)	NR	28 ± 1	Restriction to 800 kcal/day	8	CT L4-L5 (cm²)	93 ± 35 / 58 ± 26	78 ± 8 / 66 ± 7
Fujioka et al.[98]	LCD in visceral fat obesity LCD in subcutaneous fat obesity	14 (0/14) 26 (0/26)	39.6 ± 9.4 37.1 ± 9.9	34.3 ± 3.2 36.0 ± 5.7	Gradual decrease over 8 weeks to 800 kcal/day restriction, and rise to ~1100 kcal/day before discharge	8	CT (l)	6.9 ± 3.1 / 4.3 ± 2.9 3.9 ± 1.7 / 2.6 ± 1.1	83.9 ± 12.8 / 71.9 ± 10.4 87.6 ± 17.3 / 75.3 ± 15.1
Gasteyger et al.[99]	LCD in women LCD in men	85 (0/85) 26 (26/0)	Median 43 (21-67) 41 (20-61)	Median 37.3 (31.4 - 48.8) 36.6 (33.5 – 41.9)	Restriction to 800-1000 kcal/day	8	MRI L4-L5 (cm²)	123 (44-288) / -23.7% 162 (73-265) / -38.4%	Only %loss: -6 ± 5% 0 ± 2%
Giannopoulou et al.[49]	LCD	11 (0/11)	57 (no SE)	35.9 (2.2)	Reduction of 600 kcal/day	14	MRI (cm³)	4785 (480) / 4425 (435)	92.4 (5.9) / 88.8 (5.7)

Reference	Groups	N (M/F)	Age (years)	BMI (kg/m²)	Caloric restriction	Duration (weeks)	Assessment VAT	Results VAT (pre / post)	Weight (kg) (pre/post)
Goss et al.[100]	High glycemic load LCD Low glycemic load LCD	29 (14/15) 40 (17/23)	34.6 ± 8.1 35.6 ± 4.3	30.9 ± 4.5 32.4 ± 4.1	8 weeks eucaloric diet 8 weeks hypocaloric diet with a 1000 kcal-deficit	8	CT L4-L5 (cm²)	80.6 ± 48.3 / 82.4 ± 57.9 89.5 ± 46.3 / 81.5 ± 49.4	94.3 ± 20.4 / 89.4 ± 20.9 98.4 ± 17.9 / 92.9 ± 18.1
Gray et al.[101]	VLCD	10 (0/10)	37 ± 4	35.1 ± 2.1	Restriction to 650 kcal/day	10	MRI (cm²)	96 ± 36 / 70 ± 26	90.6 ± 8.1 / -10.6 ± 3.8
Gu et al.[102]	VLCD	46 (27/19)	NR	32.6 ± 0.6	Restriction to < 800 kcal/diet	8	MRI L4-L5 (cm²)	113.9 (5.8) / 79.8 (3.7)	96.1 (2.7) / 87.4 (2.5
Haufe et al.[103]	Reduced carbohydrate LCD Reduced fat LCD	52 (8/44) 50 (10/40)	Subgroups: 42 ± 9 and 45 ± 8 44 ± 9 and 46 ± 9	Subgroups: 32.0 ± 3.3 and 35.6±4.7 31.9 ± 3.9 and 33.9 ± 3	Reduction of ~30% baseline food (to a minimum of 1200 kcal)	26	MRI (kg)	1.8 ± 1.1 / 1.4 ± 0.9 1.9 ± 1 / 1.5 ± 0.9	95.0 ± 15.9 / 89.5 ± 14.9 93.6 ± 17.3 / 89.4 ± 17.0
Ibanez et al.[104]	LCD Control	12 (0/12) 9 (0/9)	51.4 ± 5.5 50.2 ± 6.8	34.6 ± 3.4 35.0 ± 3.6	Reduction of 500 kcal/day	16	MRI (cc)	3340 ± 977 / 2724 ± 1052 3175 ± 1122 / 3157 ± 1073	88.0 ± 15.2 / 82.3 ± 14.0 88.9 ± 11.4 / 88.8 ± 10.5
Jang et al.[105]	LCD	177 (NR)	40.0 (1.04)	27.1 (0.22)	Reduction of 300 kcal/day	12	CT L4 (cm²)	88.3 (2.81) / 77.8 (2.58)	71.1 (0.69) / 67.8 (0.58)
Janssen et al.[106]	Men, LCD Women, LCD	10 (10/0) 10 (0/10)	45.6 (2.1) 39.6 (2.4)	31.6 (0.9) 34.5 (1.4)	Reduction of 1000 kcal/day from baseline isocaloric diet	16	MRI 5 cm below L4-L5 to 15cm above L4-L5 (cm²)	188 (22) / -58 (10) 142 (17) / -51 (7)	98.1 (3.5) / -12% 92.9 (5.0) / -12%
Kanai et al.[107]	LCD	26 (0/26)	50 ± 13	33.7 ± 3.1	Restriction to 1200 kcal/day	12	CT umbilicus (cm²)	168 ± 12 / 124 ± 65	81.3 ± 12.1 / 71.9 ± 10.0
Kim et al.[108]	LCD in wild type LCD in only UCP3 variant	224 (144/110) (entire study)	52.7 (1.31) 52.4 (1.05)	25.9 (0.29) 25.8 (0.29)	Reduction of 300 kcal/day	12	CT L1 (cm²)	274.1 (10.4) / 254.0 (10.6) 296.8 (10.5) / 276.7 (9.6)	69.3 (1.17) / 65.9 (1.17) 69.4 (1.06) / 66.1 (1.04)

	LCD in only β3-AR variant LCD in both variants		55.4 (1.52) 54.3 (1.65)	25.9 (0.64) 25.4 (0.51)				281.9 (10.5) / 273.2 (9.6) 281.0 (10.5) / 272.3 (10.5)	67.4 (1.69) / 63.9 (1.68) 70.0 (2.13) / 66.7 (2.09)
Reference	**Groups**	**N (M/F)**	**Age (years)**	**BMI (kg/m^2)**	**Caloric restriction**	**Duration (weeks)**	**Assessment VAT**	**Results VAT (pre / post)**	**Weight (kg) (pre/post)**
Kim et al.[109]	LCD	27 (27/0)	45.8 (1.7)	30.5 (0.7)	Average restriction to 1547 kcal/day	12	CT umbilicus (cm^2)	195.1 (14.2) / 129.4 (10.9)	89.4 (2.4) / 79.9 (2.7)
Kockx et al.[110]	LCD	50 (25/25)	38.4 ± 5.5	31.3 ± 4.5	Reduction of 1000 kcal/day	13	MRI (cm^2)	98 ± 31 / 66 ± 26	85.9 ± 8.8 / 74.9 ± 8.9
Laaksonen et al.[111]	VLCD	20 (9/11)	46.7 ± 8.7	35.8 ± 9.5	Restriction to 800 kcal/day	9	CT L4 (cm^2)	216 ± 49 / 148 ± 31	101.3 ± 12.0 / 86.4 ± 9.6
Langendonk et al.[112]	VLCD in lower body obese VLCD in upper body obese	8 (0/8) 8 (0/8)	35.0 (1.7) 38.3 (2.9)	33.2 (1.6) 33.9 (1.1)	Restriction to 478 kcal/day	17	MRI L4-L5 (cm^2)	303 (37) / 155 (25) 583 (77) / 359 (47)	93.4 (5.0) / 79.2 (4.7) 94.1 (3.0) / 79.7 (2.3)
Larson-Meyer et al.[113]	Control LCD	11 (5/6) 12 (6/6)	37 (7) 39 (5)	27. 8 (2.0) 27.8 (1.4)	Reduction of -25% from baseline energy requirements	24	CT L4-L5 (kg)	2.9 (0.4) / 2.8 (0.4) 3.2 (0.5) / 2.3 (0.4)	81.8 (2.8) / 81.9 (2.8) 81.0 (3.3) / 72.6 (3.1)
Lee et al.[114]	LCD	33 (0/33)	32.4 ± 8.5	27.1 ± 2.3	Restriction to 1200 kcal/day	12	CT L4-L5 (cm^2)	79.6 ± 28.3 / 76.9 ± 29.1	70.2 ± 8.2 / 68.2 ± 6.4
Leenen et al.[115]	LCD in women LCD in men	33 (0/33) 27 (27/0)	39 ± 5 40 ± 6	31.3 ± 2.2 30.7 ± 2.2	Reduction of 1000 kcal/day	13	MRI (cm^2)	103 ± 35 / -33 ± 21 155 ± 38/ -61 ± 26	86.9 ± 7.6 / -12.4 ± 4.3 97.4 ± 8.0 / -13.5 ± 3.5
Maki et al.[116]	LCD with diacylglycerol supplements LCD with triacylglycerol supplements	65 (25/40) 62 (25/38)	49.9 ± 11.4 48.1 ± 11.2	34.5 ± 3.7 33.9 ± 3.7	Individual diet with reduction of 500-800 kcal/day	24	CT L4-L5 (cm^2)	150.4 ± 10.7 / -38 ± 3 160.6 ± 9.9 / -17 ± 8	NR
Murakami et al.[117]	LCD	18 (10/8)	48.2 (1.9)	27.8 (0.5)	Restriction to 1000-1500 kcal/day (women); 1500-1700 kcal/day (men)	12	CT (cm^2	130.6 (16.1) / 97.9 (11.4)	72.5 (2.2) / 66.4 71.5 (2.0) /

Reference	Groups	N (M/F)	Age (years)	BMI (kg/m²)	Caloric restriction	Duration (weeks)	Assessment VAT	Results VAT (pre / post)	Weight (kg) (pre/post)
									62.9 (1.8)
Ng et al.[118]	LCD	20 (20/0)	NR	35.2 (1.0)	Restriction to 1467 kcal/day	14	MRI (kg)	7.1 (0.5) / 5.4 (0.4)	109.3 (2.3) / 96.0 (2.7)
Nicklas et al.[119]	LCD	34 (0/100)	58.4 ± 6.0	33.9 ± 4.0	Reduction of 400 kcal/day	20	CT L4-L5 (cm³)	2369 ± 870 / -612 ± 338	91.8 ± 10.4 / -11.8 ± 4.1
Okhawara et al.[120]	LCD	9 (9/0)	50.1 ± 12.9	27.9 ± 2.3	Restriction to 1680 kcal/day	13	CT umbilicus (cm²)	186 ± 41.9 / 97 ± 17.7	81.1 ± 5.6 / 69.4 ± 4.4
Okura et al.[121]	LCD in intra-abdominal fat obesity LCD in subcutaneous fat obesity	31 (0/31) 34 (0/34)	NR	29.4 ± 3.2 27.8 ± 2.0	Restriction to 1130 kcal/day	14	CT L4-L5 (cm²)	148 ± 41 / -37 ± 19 68 ± 24 / -23 ± 17	71.5 ± 8.8 / -7.0 ± 2.4 67.5 ± 5.9 / -7.9 ± 3.6
Pierce et al.[122]	LCD Control	26 (15/11) 14 (9/5)	49.5 (2.5) 40.8 (3.3)	29 (1) 31 (1)	Individualized diet with pre-set weight loss goal (minimum calories 1200 kcal/day)	12	CT L4-L5 (cm²)	128 (10) / 84 (7) 150 (19) / 154 (19)	85 (3) / 76(2) 94 (3) / 95(3)
Purnell et al.[123]	LCD	21 (21/0)	65 (60-75)	31 (27-37)	Restriction to 1200 kcal/day	13	CT umbilicus (cm²)	201 ± 51 / 153 ± 49	96 ± 11 / 86 ± 11
Purnell et al.[124]	LCD	13 (5/8)	NR	35 ± 4.8	Restriction to 1000 kcal/day for 3 months, thereafter gradual transition during 2 weeks to a solid diet	13	CT umbilicus (cm²)	146 ± 57 / 77 ± 47	99 (no SD) / 82
Riches et al.[125]	LCD Isocaloric diet	12 (12/0) 14 (14/0)	NR	34.1 (1.0) 34.6 (0.7)	Restriction to 1200 kcal/day	14	MRI L3 (cm²)	322.8 (23.4) / 222.1 (22.1) 309.6 (20.3) / 296.7 (15.1)	106.3 (4.1) / 95.9 (4.0) 108.2 (2.4) / 109.1 (2.6)
Ross et al.[26]	LCD	11 (11/0)	46.8 ± 7.6	31.6 ± 2.7	Reduction of 1000 kcal/day	16	MRI (l)	4.7 ± 1.6 / -1.5 ± 0.8	Only %loss -11.5%
Rossi et al.[126]	LCD	24 (13/11)	46.7 ± 14.3	35.4 ± 4.5	Reduction of 500 kcal below daily energy expenditure	13-26	MRI L4-L5 (cm²)	174.8 ± 94.7 / 118.9 ± 76.3	98.4 ± 15.9 / 89.7 ± 14.8
Ryan et al.[127]	LCD in NGT	29 (0/29)	60 (1)	32.8 (0.9)	Reduction of 500 kcal/day	26	CT L4-L5	146.9 (12.6) / 127.1 (11.1)	88.3 (2.8) / 81.9 (2.9)

	LCD in IGT	17 (0/17)	65 (2)	32.7 (1.2)			(cm²	148.7 (11.6) / 126.5 (9.7)	84.4 (3.7) / 77.0 (3.3)
Reference	**Groups**	**N (M/F)**	**Age (years)**	**BMI (kg/m²)**	**Caloric restriction**	**Duration (weeks)**	**Assessment VAT**	**Results VAT (pre / post)**	**Weight (kg) (pre/post)**
Ryan et al.[128]	LCD	23 (0/23)	56 (1)	Range: 25-48	Reduction of 250-350 kcal/day	26	CT L4-L5 (cm²)	140.4 (12.1) / 115.1 (11.5)	88.8 (3.8) / 83.6 (3.7)
Saiki et al.[129]	LCD	22 (16/6)	53.6 ± 8.4	30.4 ± 5.3	Restriction to 740 or 970 kcal/day	4	CT L4-L5 (cm²)	233.1 ± 66.5 / 191.0 ± 67.0	85.2 ± 17.0 79.0 ± 17.2
Shin et al.[130]	LCD in MAO LCD in MHO	106 (0/106) 23 (0/23)	39.8 ± 12.2 36.4 ± 11.2	28.0 ± 2.6 27.2 ± 1.94	Reduction of 300 kcal/day	12	CT L4 (cm²)	95.1 ± 34.0 / 89.5 ± 33.4 69.0 ± 18.5 / 63.6 ± 15.5	71.2 ± 8.3 / -3.16±4.08% 70.5 ±5.1 / -2.83±2.74%
Snel et al.[131]	VLCD	14 (8/6)	53 (2)	35.2 (1.1)	Restriction to 450 kcal/day	16	MRI L5 (ml)	553 (47) / 228 (46)	107 (4) / 83 (4)
Stallone et al.[132]	LCD	11 (0/11)	52 (no SD)	37.0 ± 4.5	3 months restriction 400-800 kcal/day, 2 months refeeding, 1 month 1200-1500 kcal/day	26	CT L4 (cm²)	148 ± 75.4 / -52.9 ± 38.0	94.8 ± 10.8 / -18.8 ± 6.9
Svendsen et al.[133]	VLCD	10 (0/10)	Median (range) 34 (28-27)	NR(minimum for each subject: 28)	Restriction to 500-600 kcal/day	8	CT umbilicus (cm²)	125.9 ± 115.2 / 109.8 ± 90.3	Only %loss: -11%
Tchernof et al.[134]	LCD	25 (0/25)	57.2 ± 5.5	35.3 ± 4.0	Restriction to 1200 kcal/day	13.9	CT L4-L5 (cm²)	202 ± 73 / 128 ± 57	93.0 ± 10.7 / 79.5 ± 11.0
Tiikainen et al.[135]	Women with high liver fat Women with low liver fat	11 (0/11) 12 (0/12)	37 (1) 37 (2)	33 (1) 32 (10)	Reduction of 600-800 kcal/day	18-19	MRI (cm³)	1665 ± 141 / -383 ± 67 1497 ± 167 / -441 ± 122	Only %loss: -8.4 (0.2)% -8.3 (0.2)%
Toledo et al.[136]	LCD	7 (3/7)	46.1 (2.0)	33.4 (1.2)	Reduction of 25% of calorie intake (both groups)	19.2	CT L4-L5 (cm²)	207.9 (24.7) / 172.1 (32)	95.0 (4.3) / 84.4 (2.7)
Van Dam et al.[137]	VLCD in ovalutory responders VLCD in ovalutory non-responders	9 (0/9) 6 (0/6)	30 (2.5) 30 (1.8)	37.5 (1.6) 41.9 (3.6)	Restriction to 470 kcal/day	8	MRI L4-L5 (cm²)	138 (17) / 91 (18) 166 (29) / 114 (217)	NR

Reference	Groups	N (M/F)	Age (years)	BMI (kg/m²)	Caloric restriction	Duration (weeks)	Assessment VAT	Results VAT (pre / post)	Weight (kg) (pre/post)
Van der Kooy et al.[138]	Obese women Obese men	40 (0/40) 38 (38/0)	39 ± 6 40 ± 6	31.3 ± 2.3 30.7 ± 2.3	Reduction of 1000 kcal/day	13	MRI (cm²)	106 ± 50 / -37 ± 29 154 ± 40 / -61 ± 25	86.5 ± 8.7 / -12.6 ± 3.9 98.3 ± 7.2 / -13.3 ± 3.0
Viljanen et al.[139]	VLCD	16 (4/12)	45 (2.5)	33.3 (1.1)	Restriction to 550 kcal/day	6	MRI L2/L3 (kg)	1.6 (0.2) / 1.2 (0.1)	95.7 (3.3) / 84.6 (2.9)
Vissers et al.[140]	LCD Control	20 (5/15) 21 (5/16)	45.5 ± 13.1 44.8 ± 11.4	32.9 ± 3.1 30.8 ± 3.4	Reduction of -600 kcal/day (for all diet groups)	26	CT L4-L5 (cm²)	134.8 ± 57.3 / -26/3 ± 29.2 111.5 ± 47.6 / -3.6 ± 20.5	92.1 ± 11.1 / - 6.1 ± 4.6 88.6 ± 15.9 / + 0.9 ± 3.4
Wahlroos et al.[141]	VLCD (n=13)	13 (0/13)		45 ± 7	Restriction to 450-800 kcal/day	6	MRI L4-L5 (mm²)	22400±11300/ 18300±8700	118.8 ± 16.6/ 110.0 ± 17.5
Weinsier et al.[142]	LCD in white women LCD in black women	23 (0/23) 23 (0/23)	37.0 ± 5.9 35.5 ± 5.9	29.0 ± 1.5 28.7 ± 1.8	Restriction to 800 kcal/day	22	CT L4-L5 (cm²)	113.0 ± 39.2 / 67.0 ± 23.8 67.6 ± 18.0 / 41.8 ± 16.9	79.1 ± 5.0 / 66.0 ± 4.8 78.2 ± 8.9 / 65.6 ± 7.7
Zamboni et al.[143]	VLCD and LCD	16 (0/16)	38.8 ± 14.1	38.2 ± 6.9	First two weeks restriction to 307 kcal/day (VLCD) LCD for a mean duration of 14 weeks with restriction to 1003 kcal/day	16	CT L4 (cm²)	167 ± 80.3 / 93.3 ± 61.6	104.3 ± 18.1 88.1 ± 11.6

Table 2. Characteristics of included studies (n=8) that directly compared exercise training with hypocaloric diet

Reference	Groups	N (M/F)	Age (years)	BMI (kg/m²)	Intensity (exercise studies) Caloric restriction (hypocaloric diet studies)	Frequency/ duration per session (for exercise only)	Duration (weeks)	Assess ment VAT	Results VAT (pre / post)	Results weight (kg) (pre / post)
Christiansen et al.[144]	Aerobic exercise LCD	19 (9/10) 19 (10/9)	37.2 ± 7 35.6 ± 7	33.3 ± 4 35.3 ± 4	70% of HRR Restriction to 600 kcal during 8 weeks	60-75 min per session, 3x/week	12 8 weeks diet, 4 weeks weight mainte-nance	MRI	3038.3±1086.1 / -18.4% ± 2.8 3437.5±1516.2 / -30.2% ± 3.2	100.9 / -3.5kg 107.8 / -12.3
Coker et al.[145]	Aerobic exercise LCD Control	6 (2/4) 6 (3/3) 5 (3/2)	55 (2) 58 (2) 59 (2)	32 (1) 30 (0) 31 (1)	50% of VO2peak Reduction of 1000 kcal/week in week 1, and a further addition of 500 kcal each week until a reduction of 2500 kcal/week was reached	Depending on energy expenditure (week 1: 1000 kcal with a gradual increase to 2500 kcal/week)	12	CT (cm²)	245 (31) / 228 (24) 199 (12) / 170 (11) 198 (17)/ 170 (11)	91 (3) / 91 (3) 86 (2) / 81 (2) 89 (4) / 91 (4)
Koo et al.[146]	LCD Aerobic exercise Control	19 (0/19) 13 (0/13) 18 (0/18)	57 ± 8 59 ± 4 57 ± 8	27.1 (no SD) 25.5 28.5	Restriction 1200 kcal/day Depending on energy expenditure	 7 days/week, 120 minutes	12	CT L4-L5 (cm²)	157.8 / 151.7 162.4 / 146.9 172.4 /163.4	67.4 (no SD) / 62.4 64.0 / 62.4 66.0 / 65.8
Nordby et al.[147]	Aerobic training LCD	12 (12/0) 12 (12/0)	28 (1) 32 (2)	28.3 (0.3) 28.0 (0.4)	65% HRR, alternated with HIIT (bouts at 85% HRR) Reduction of 600 kcal/day	7 days/week, duration depended on energy expenditure (600	12	MRI T11-L5 (L)	1.60 (0.12) / -0.53 1.83 (0.18) / -0.25	94.5 (2.3) / 88.6 (2.3) 91.2 (1.8) / 85.9 (2.2)*

	Control	12 (12/0)	31 (2)	28.0 (0.4)		kcal per session)			2.12 (0.21) / -0.02	92.2 (2.7) / 92.1 (2.5)
Reference	**Groups**	**N (M/F)**	**Age (years)**	**BMI (kg/m²)**	**Intensity (exercise studies)** **Caloric restriction (hypocaloric diet studies)**	**Frequency/ duration per session (for exercise only)**	**Duration (weeks)**	**Assess ment VAT**	**Results VAT (pre / post)**	**Results weight (kg) (pre / post)**
Oh et al.[148]	Aerobic exercise LCD	108 (108/0) 104 (104/0)	NR (adults)	29.2 (0.3) 29.4 (0.4)	60-85% of maxHR Restriction to 1680 kcal/day	3 days/week, 40-60 minutes	12	CT (cm²)	178.1 (5.5) / 156.4 (5.0 159.0 (6.2) / 123.3 (5.2)	85.2 (1.0) / 82.6 (1.0) 84.9 (1.3) / 77.7 (1.2)
Racette et al.[149]	LCD Aerobic exercise Control	19 (7/12) 19 (7/12) 10 (4/6)	55.6 (0.8) 58.8 (0.6) 56.0 (0.9)	27.2 (0.6) 27.2 (0.4) 27.9 (0.4)	Reduction of 16% of caloric intake 3 months, reduction of 20% 9 months Depending on energy deficit (same reduction as diet groups)	7 days /week, duration depending on energy deficit	52	MRI (cm³)	824.7 ± 143,4 / 633.5 ± 95.6 1123.5 ± 131.5 / 513.9 ± 107.6 1159.4 ± 203.4 / 1004 ± 155	78.5 (2.3) / 70.5 (2.3) 77.5 (2.4) / 71.0 (2.4) 81.9 (3.7) / 80.0 (3.7)
Ross et al.[150]	LCD Aerobic exercise Control	15 (0/15) 17 (0/17) 10 (0/10)	43.9 ± 4.9 43.2 ± 5.1 43.7 ± 6.4	31.9 ± 2.8 32.8 ± 3.9 32.4 ± 2.8	Reduction of 500 kcal/day ~80% maxHR	7 days/week, 63 minutes	14	MRI (kg)	2.4 ± 1.2 / 1.9 ± 1.0 2.3 ± 0.8 / 1.6 ± 0.7 2.3 ± 0.9 / 2.2 ± 0.9	86.6 ± 10.9/ 80.1 ± 11.2 86.8 ± 10.9/ 80.9 ± 10.8 88.1 ± 8.2 / 88.6 ± 7.4
Ross et al.[151]	LCD Aerobic exercise Control	14 (14/0) 16 (16/0) 8 (8/0)	42.6 ± 9.7 45.0 ± 7.5 46.0±10.9	30.7 ± 1.9 32.3 ± 1.9 30.7 ± 1.6	Reduction of 700 kcal/day ~75% max HR	7 days per week, 60.4 minutes	14	MRI L4-L5 (kg)	3.2 ± 1.0 / -25.2 (2.0)% 3.9 ± 1.0 / -27.5 (1.9)% 4.1 ± 1.7 / -1.9 (2.7)%	96.1 ± 8.7 / -7.7 (0.2)% 101.5±7.7 / -7.5 (0.3)% 96.7 ± 9.0 / -0.2 (0.4)%

Data depicted as: Mean ± standard deviation or Mean (standard error). Post value –(x) represents absolute decrease in VAT or weight (unless stated otherwise).
Abbreviations: M=male; F=female; BMI=body mass index; NR= not reported; maxHR = maxium heart rate; HRR = heart rate reserve; min = minutes; CT = Computed Tomography; MRI = magnetic resonance imaging; LCD=low calorie diet

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